PREDICTION OF WRINKLING USING FINITE ELEMENT SIMULATION

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ABSTRACT

Deep drawing is a process for shaping flat sheets into cup-shaped articles without fracture or excessive localized thinning. The design and control of a deep drawing process depends not only on the work piece material, but also on the condition at the tool work piece interface, the mechanics of plastic deformation and the equipment used. This final project is about prediction of wrinkling in deep drawing part. The prediction methods can be broadly divided into two categories which is by experimental and simulation. The project deals with the Finite Element Analysis (FEA) and one step simulation of cup 50 mm using Altair Hyperform. In this project, the effect of some variables like blank holder force, blank thickness and drawn depth are investigate on flange wrinkling. Based on the result, the first analysis shows that wrinkle will occurred when the blank holder force is low. By increasing the blank holder force, the wrinkle is reducing. Second analysis shows that more thicker part will decreased tearing ratio due to the strength and stiffness of material. The last analysis give a result on effect of blank holder force and drawn depth on flange wrinkling where as if the depth increased, the percentage of wrinkling also increased. FEA software can be effectively used not only to predict the extent of damage, but damage control measures can also be simulated to suggest appropriate action to be taken at forming stages.

ABSTRAK

Penarikan yang mendalam adalah satu proses untuk membentuk kepingan rata ke dalam artikel-artikel yang berbentuk cawan tanpa patah atau berlebihan setempat menipis. Reka bentuk dan kawalan proses penarikan yang mendalam bukan hanya bergantung kepada bahan bahan kerja, tetapi juga kepada keadaan di bahan kerja, mekanik ubah bentuk plastik dan peralatan yang digunakan. Projek akhir semester ini adalah mengenai peratusan ramalan kedutan di bahagian lukisan yang mendalam. Kaedah ramalan boleh dibahagikan secara umumnya kepada dua kategori iaitu dengan eksperimen dan simulasi. Projek ini memerlukan Analisis Unsur Terhingga (FEA) dan simulasi cawan 50 mm menggunakan Altair Hyperform. Dalam projek ini, kesan beberapa pembolehubah seperti kuasa pemegang kosong, ketebalan kosong dan mendalam disediakan adalah menyiasat kedutan bebibir. Berdasarkan keputusan dari analisis pertama, peratusan kedutan di bahagian lukisan mendalam akan berlaku apabila kuasa pemegang kosong di kuarangkan. Apabila kuasa pemegang kosong di tingkatkan, peratusan kedutan menjadi semakin kurang. Analisis kedua menunjukkan semakin tebal bahan kerja, semakin sukar bahan kerja itu untuk merekah. Analisis terakhir menunjukkan apabila kedalaman bahan kerja bertambah, peratusan kedutan juga bertambah.

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A = area to be cut

L = length of material

T = Thickness of material

D = diameter of blank

W = width of rectangle

C = Clearance (per side)

Ø = Diameter

d = Depth of draw

LIST OF ABBREVIATIONS

JIS	Japaneese Industrial Standards
HB	Hardness Brinell
CAD	Computer aided design
mm	millimeters
CNC	Computer Numerical Control
rpm	Revolution per minute
2D	Two dimensional
3D	Three dimensional
FEA	Finite Element Analysis
FEM	Finite Element Model

CHAPTER 1

INTRODUCTION

1.1 PROJECT OVERVIEW

Sheet metal forming process is widely used in manufacturing engineering especially in an automotive industries such as making fuel tank. During the process, the sheet metal blank is subjected to plastic deformation using forming tools to shape the design. Usually in deep drawing process the depth of the part must be more than half its diameter. In deep drawing process, the blank is placed over the die and is pressed into the die cavity using a punch. A blank-holder is apply pressure to the outer section of the blank, called the flange, during the forming process. The ratio of the original blank diameter to the diameter of the shaped part is called the draw ratio. Failure in operations may result in wrinkling of the formed part. This project is to study the prediction of wrinkling in sheet metal parts. In order to predict the wrinkling, some of the variables parameters need to considered and analyze by HYPERFORM software (simulation software). Variables thickness of blank, blank holder force and depth of cup are considered in this analysis to predict the flange wrinkling.

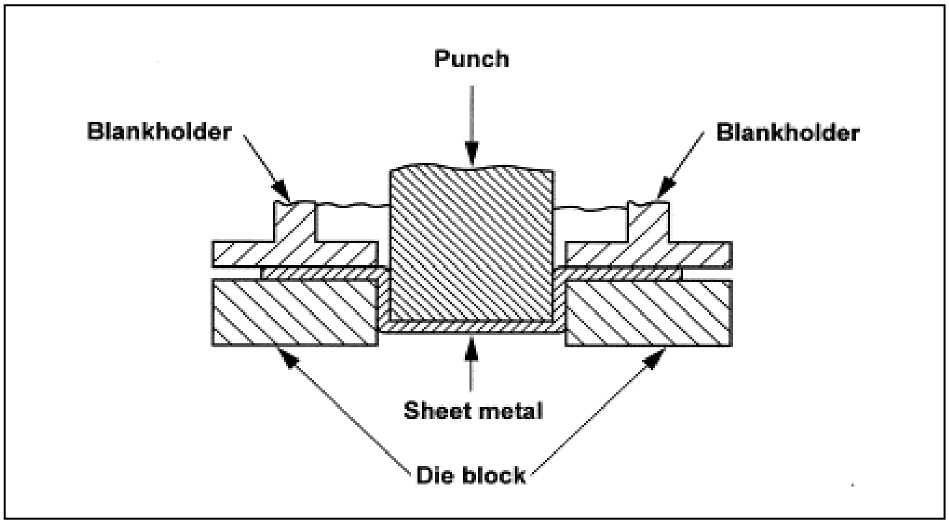


Figure 1.1 : Schematic of deep drawing operation

Source : Vukota Buljanovic, 2004

1.2 PROJECT BACKGROUND

Wrinkling is one of the most failure in forming process especially in deep drawing process. Wrinkling occurs when compressive stress in the circumferential direction reaches a critical point of instability. Severe wrinkles may damage or even destroy dies. Therefore, the prediction and prevention of wrinkling are extremely important in sheet metal forming and thus it can reduce scrap parts and minimize production cost. By measured the circumferential deflection profile at various radii from the center of the part, wrinkling failure can be detected. Wrinkling height and the number of wrinkles per profile are two parameters determining the severity of the wrinkling. Higher wrinkling heights and more wrinkles per profile indicate a more sever wrinkling condition in the formed part.

By considered the variables of parameters in deep drawing operation may result in a good formed parts. The parameters influenced in deep drawing operation are thickness of blank, blank holder force, material property, punch and die radii, surface condition and lubrication, and process factors. There are two type of wrinkling which is wall wrinkling and flange wrinkling. The flange of the blank undergoes radial drawing stress and tangential compressive stress during the stamping process, which sometimes results in wrinkles. Wrinkling is preventable if the deep drawing system and stamped part are designed properly. Figure 1.2 shows a different between flange and wall wrinkling.

Wall wrinkling **Flange wrinkling**

Figure 1.2 : Schematic of wall and flange wrinkling

Source : Vukota Buljanovic, 2004

1.3 PROBLEM STATEMENT

The appearance of dimensional deviations of shape and position of the defects in the sheet metal that have been subjected to a deep drawing especially in wrinkling failure and it represents a critical problem for the specific industry, especially for the mass production, like the machine manufacturing industry. The aim of this project is to predict the wrinkling by considered the principal aspects that effect of various factors like blank holder force, punch radius, die edge radius, and coefficient of friction on the wrinkling of cylindrical parts in deep drawing process. The initiation and growth of wrinkles are influenced by many factors such as stress ratios, the mechanical properties of the sheet material, the geometry of the work piece, and contact condition. It is difficult to analyze wrinkling initiation and growth while considering all the factors because the effects of the factors are very complex and studies of wrinkling behavior may show a wide scattering of data even for small deviations in factors. In this present project, the optimum parameters of wrinkling in the cylindrical cup deep drawing is investigated in detail by using finite element software.

1.4 OBJECTIVE

The objectives of this project is to predict wrinkling in cylindrical cup by do a simulation one step analysis on that part. Then finite element analysis is study to get the optimum parameters for a cylindrical cup. In this project, the thickness of blanks, blank holder force and height of cup are variables in order to study the effect of this parameters on flange wrinkle.

1.5 PROJECT SCOPE

The scope of this project is to study wrinkling failure in deep drawing parts. The parameters influenced to wrinkling are identified. Then simulate the drawing part and finite element is analyze towards the part. The variables thickness of blank which is 1, 2 mm are used to get the optimization of parameters. The blank holder force are calculated and height of cup are 10 and 20 mm.

1.6 PROJECT FLOW CHART

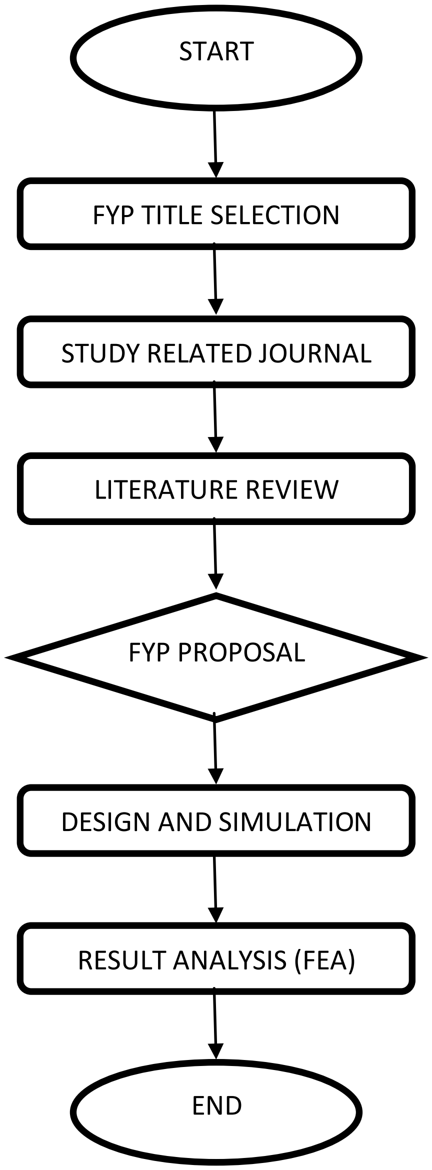


Figure 1.3 : Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter are presents about the current searching that related to the title. Firstly, theory of deep drawing will be discussed. Secondly, the parameters and possible failure in deep drawing are discussed such as fracture and wrinkling. Then, the wrinkling failure will be described consists of theory, and prevention method. At the last chapter, Finite Element Analysis will be discussed.

2.2 DEFINITION OF DEEP DRAWING PROCESS

Mostly, an automobile components are made by deep drawing process such as tank and lamp cup. Deep drawing is one of the sheet metal forming process which is to fabricate a hollow parts. In a deep drawing process, a sheet metal blank is insert and clamped between die and a blank holder. Then, a punch with a specific force is pushes a sheet metal blank into a die cavity and resulting the contoured part [9].

In order to have a success deep drawing part, the influenced parameters need to be considered such as material characteristics, friction, condition of punch and die, clearance of deformation, punch force, blank holder force and others [7]. By neglecting this parameters, wrinkling may occurs in the formed part. Wrinkling is the major failure in deep drawing part and it occurs in the wall or flange of the part. By using simulation, the optimum values of parameters can determined. It also can identify the problems areas and solution in the part, reduce tryout and manufacturing cost. Sandeep Patil and Tated, 2011 have using Altair HyperForm software to predict the various of parameters on formability of a trapezoidal cup [13].

2.3 TYPE OF FAILURE IN DEEP DRAWING PROCESS.

Failure is one of the most important aspects of material behavior, because it is directly influences the selection of a material for a particular application, the methods of manufacturing, and the service life of the component. In deep drawing process, there are some failures such as wear, fracture, and wrinkling.

2.3.1 Wear

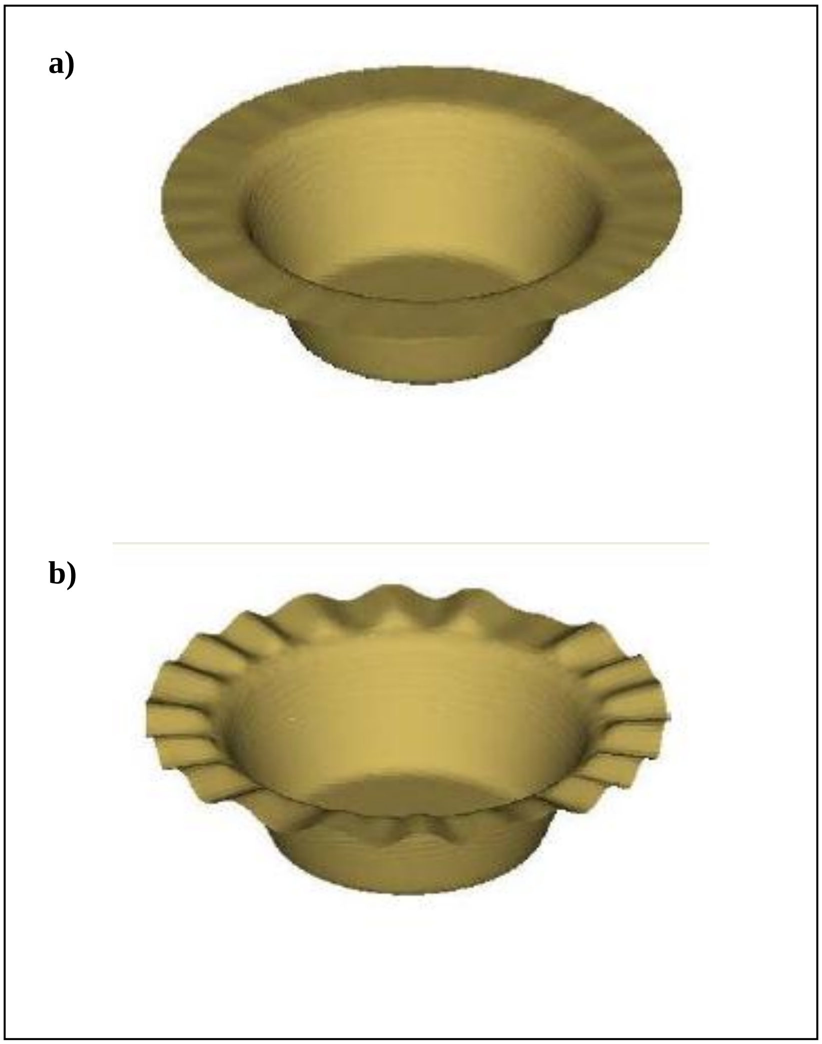
There are two types wear in deep drawing which is adhesive and abrasive wear. During sliding of the sheet metal on die, the two materials may cold weld at the top of the surface. Adhesive wear takes place when further relative movement between work piece and tools induces breakage of the cold welds inside the tool material rather than the interface.

2.3.2 Fracture

Fracture is one of the common defects during deep drawing. There is limited by fracture, so that the quantitative determination of a fracture criterion such as limit stress (or load) and limit strain is the basis for determining the limit drawing ratio to draw up a process plan and for controlling the forming operation to prevent or delay failures by fracture.

2.3.3 Wrinkling

Wrinkling is known as a failure phenomenon in forming sheet metal parts (Fig 2.1). It damage to the wall or flange area and the functioning. Thus is affect to the manufacturing cost because mostly the wrinkling part become a scrap and cannot be reprocessed [11].



a) Marginal Wrinkle (b) Wrinkle

Figure 2.1 : Wrinkling area

2.4 CLASSIFICATION OF PARAMETERS AFFECTING WRINKLING.

2.4.1 Blank holder force

The blank holder is a tool that holds the edges of the sheet metal blank in place against the top of the die while the punch forces the sheet metal into the die cavity [8]. It also used for preventing the edge of a sheet metal part from wrinkling. A high blank holder force can leads to fracture at the cup wall while low blank holder force leads to wrinkling in the flange of the cup [9]. So, it is important to meet the optimum blank holder force in order to prevent wrinkling. The blank holder force can be calculated by a formula (2.1) :

Blank holding force: $F_N = A_n . P_N$

where F_N = blank holding force (N)

A_n = blank holder area (mm^2)

$$\frac{\pi}{4}(D^2_b - d^2_p)\ (mm^2) \quad \text{(2.1)}$$

P_N = Unit blank holding pressure (N/mm^2)

$$[(\beta - 1)^2 + \frac{d_p}{200.t}]\frac{\sigma B}{400}$$

2.4.2 Draw bead

Draw beads are placed to the die (small protrusions on the die surface) in order to control the flow of the material during the forming operations. The material fills the groove, this results in a change in the strain distribution in the flange region. Thinning of the blank is achieved and compressive stresses are decreased so wrinkling is avoided.

2.4.3 Drawing Force

The drawing force formula (2.2) :

$$\boxed{F_{dr} = C \cdot s \cdot R_m \cdot n = d \cdot \pi \cdot s \cdot R_m \cdot n} \qquad (2.2)$$

F_Z	in N	drawing force
C	in mm	circumference of the drawing punch
d	in mm	punch diameter
s	in mm	sheet thickness
R_m	in N/mm^2	tensile strength
n		correction value

2.4.4 Die edge radius and clearance.

The value of clearance between punch and die must be considered in order to meet a success deep drawing part. During the forming process, the clearance between punch and die will give a desired force to the sheet metal blank. The other parameters that need to be considered is punch and die radius. The large radius can cause wrinkling to the part while the smallest radius can cause fracture or breaking the part due to the high stresses [1].

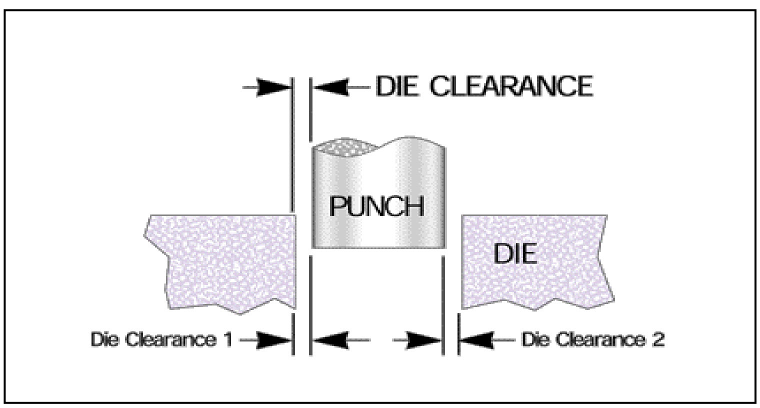


Figure 2.2 : Punch and Die clearance

Table 2.1 illustrates the absolute value for clearance depending on the type and thickness of the material.

Material thickness T (mm)	Material			
	Low Carbon Steel, copper and Brass	Medium steel 0.20 % to 0.25% Carbon	Hard steel 0.40% to 0.60% carbon	Aluminum
0.25	0.01	0.015	0.02	0.01
0.50	0.025	0.03	0.035	0.05
1.00	0.05	0.06	0.07	0.10
1.50	0.075	0.09	0.10	0.015
2.00	0.10	0.12	0.14	0.20
2.50	0.13	0.15	0.18	0.25
3.00	0.15	0.18	0.21	0.28
3.50	0.15	0.18	0.21	0.28
4.00	0.20	0.24	0.28	0.40
4.50	0.23	0.27	0.32	0.45
4.80	0.24	0.29	0.34	0.48
5.00	0.25	0.30	0.36	0.50

Table 2.1 : Value for clearance on type and thickness material

Source : Vukota Buljanovic, 2004

2.4.5 Die Cavity

The design of the punch and die cavity can be optimized to reduce the probability of wrinkling. Choosing a flange radius that is just large enough to prevent cracking can minimize the potential for wrinkles. Additionally, considering minimizing the part complexity and any asymmetry can also help. Incorporating a multi-step drawing process offers a variety of advantages in preventing wrinkling in deep-drawn parts. Designing the blank geometry to minimize excess material can reduce the potential for wrinkling. The sheet metal blank has an inherent grain structure, so the stresses can vary depending on the design of the die and the orientation of the grain. Adjusting the grain in an asymmetrical design to minimize the compound of grain stresses and the general stresses of the deep draw process is something to take into consideration.

.2.4.6 Limit Draw Ratio

The critical forming parameter for cylindrical cup drawing is the limit drawing ratio (LDR), which is the ratio of the maximum blank diameter to punch diameter that can be drawn in one draw operation. The limit draw ratio is used to determine how many drawing operations are necessary to produce a drawn part, the correction value $n = f$ (draw ratio) to calculate the drawing force (2.3).

$$\boxed{\text{LDR} = \frac{\text{Maximum Blank Diameter, D}}{\text{Punch Diameter, d}}} \dashrightarrow \quad (2.3)$$

2.4.7 Blank thickness and shape

Blank thickness is important to give a clearance between punch radius and die radius. Without an optimum clearance, ironing will occur. Ironning can be defined as thinning of the blank at the die cavity. So, clearance should be %25 larger than the initial blank thickness in order to prevent the wrinkling. The limiting drawing ratio decreased as sheet thickness decreased while blank holder force increased as the sheet thickness decreased. It is seen that BHF is strongly influenced by sheet thickness. [13]

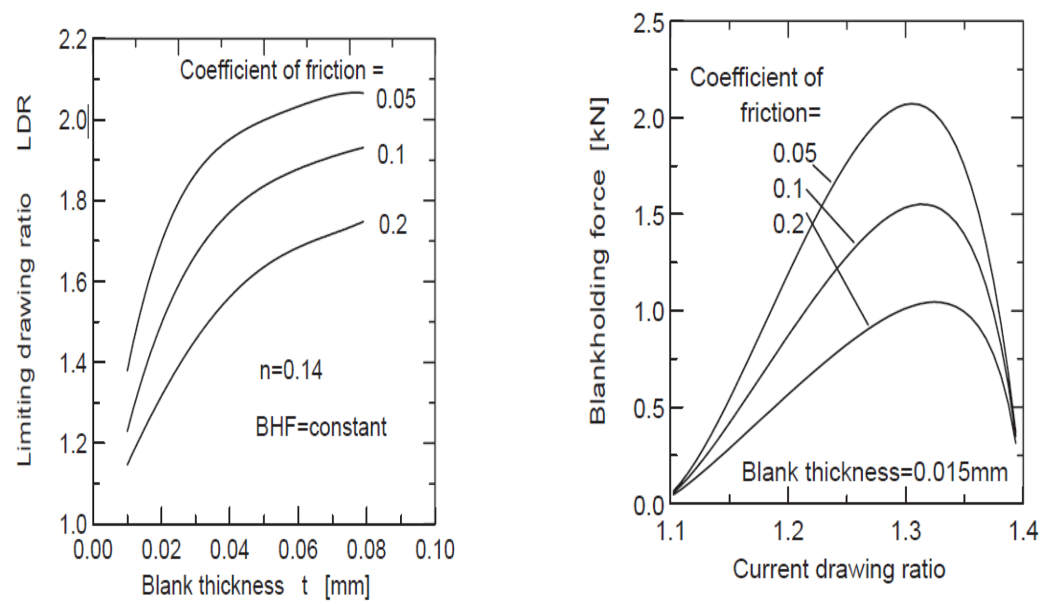


Figure 2.3 : Diagram sheet thickness on the limit drawing ratio and blankholder force

2.4.8 Friction Coefficient

Surface conditions of each component can be tailored to improve overall performance. Lubricants reduce the friction between the blank and the punch and die cavity and can be liquid (wet) or films (dry). Generally, they are applied to the blank before drawing. While lubricants can facilitate the metal flow into the die cavity, consider increasing the blank holding force to account for the reduced friction.

2.4.9 Summary of wrinkling parameters

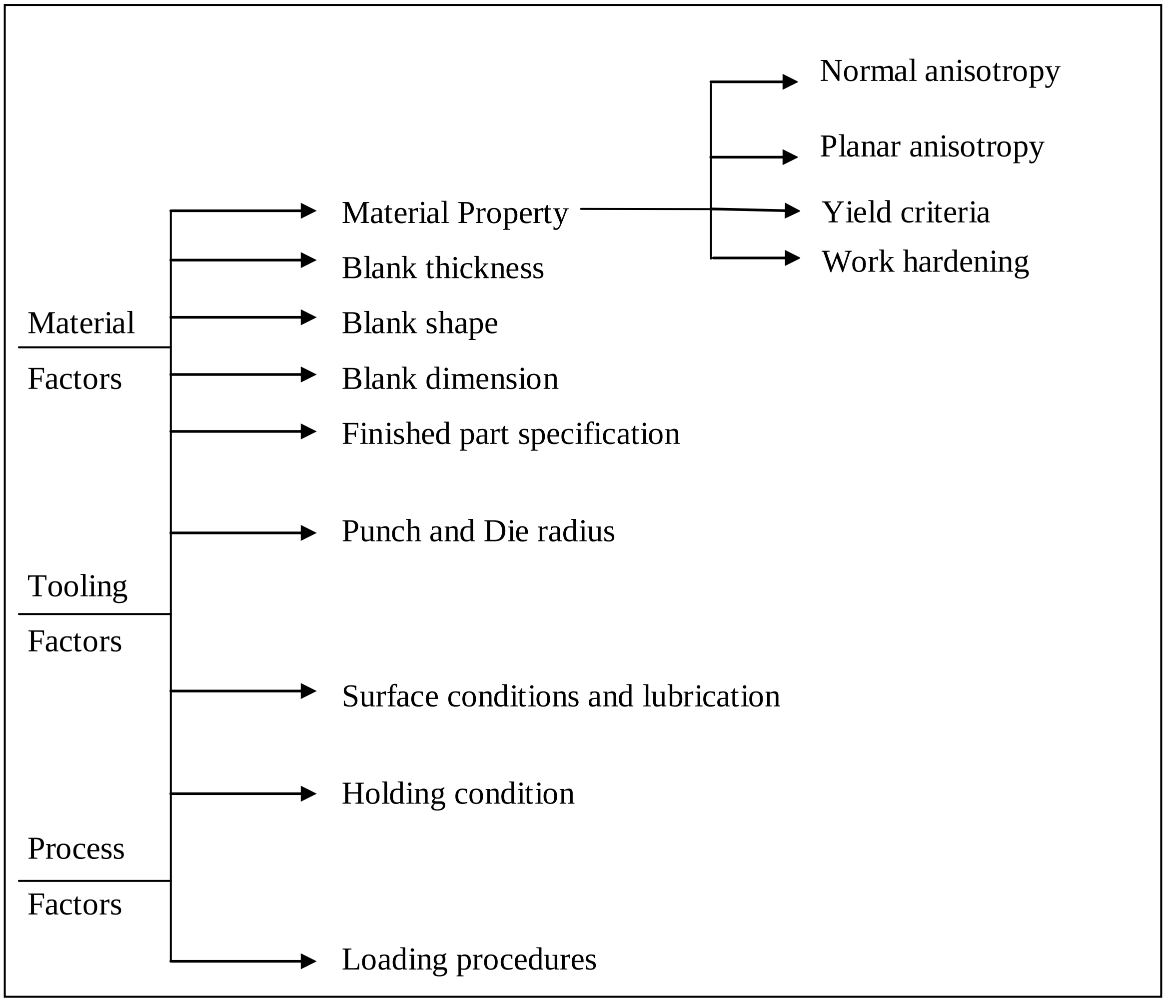


Figure 2.4 : Summary of wrinkling parameters

2.5 THEORY OF WRINKLING

Wrinkling is often observed in sheet metal part. Wrinkling also one of the common failure in deep drawing parts because of the trend toward thinner, and high strength sheet metal. It occurs in areas which are not in contact with tool. It can lead to expensive redesign and remanufacture of tooling, lost press and operator time, and scrapped parts. It is important to predict wrinkling in Finite Element Analysis by simulate the sheet metal parts especially for cylindrical cup. However, prediction of the specific conditions that will result in wrinkling is a difficult task. There have been a large number of theoretical, experimental and numerical investigations of wrinkling in single step drawing of relatively thin sheet. [2]

2.5.1 Previous study

Xi Wang and Jian Cao [5] have analyze wrinkling by applied on bending of thin walled product edges. They concluded that wrinkling reduces when the length of bent edge is increased, and that thickness has no influence onto number of wrinkles, but increased thickness leads to increase in critical length of bend edge.

Janardhan Reddy, Dr.G.C.M. Reddy [1] also study the same title which is the effect of tooling parameters on wrinkling failure. The different between the previous study are the experimental. The previous study are using finite element method to solve wrinkling. The brothers are use 112.4mm diameter and 42.5mm height of cup, 5mm blank thickness, 9.0 ton of drawing force. The Blank Holder plate is supported by 8 cushion pins which are transfer the load from the die cushion to the Blank Holder supporting plate. The BHF was measured by providing load cells at sides of the cylindrical Blank Holder. As a result, the wrinkle height increases along with the deep drawing depth.